Preliminary Analysis of the Feasibility of Transferring New Longline Technology to Small Artisanal Vessels off Northeastern Brazil

F. H. V. HAZIN, M. K. BROADHURST, and H. G. HAZIN

Introduction

Fishing communities along the northeast coast of Brazil rely heavily on inshore stocks of several commercially important species and have adopted a range of simple fishing methods for their exploitation. Most fishing occurs within 20 km of the coast using small simple wooden vessels (6–12 m), powered by 3- or 4-cylinder diesel motors, and includes handlining for benthic species of fish (i.e. snappers, *Lutjanus* spp.; weakfish, *Cynoscion* spp.; and groupers, *Mycteroperca* spp.) and more commonly, the use of gillnets and baited bamboo traps to target spiny lobsters (*Panulirus argus* and *P. laevicauda*) (Paiva et al., 1971). No regulation of fishing effort, combined with recruitment failures due to degradation of nursery areas and over fishing, has meant that most stocks are currently exploited well beyond sustainable levels (Dias Neto and Dornelles, 1996). A steady decline in catches over the past 20 years has resulted in serious social and economic conditions for many fishing communities (Dias Neto and Dornelles, 1996).

The authors are with the Universidade Federal Rural de Pernambuco-UFRPE, Departamento de Pesca, Laboratório de Oceanografia Pesqueira, Av. Dom Manuel de Medeiros, s/n, Dois Irmãos, Recife-PE, Brazil, CEP: 52.171-900. e-mail: fhvhazin@truenet.com.br

ABSTRACT—The catches of three longliners, including two recently converted small artisanal vessels and one large leased foreign longliner, were compared to provide some indication of the feasibility of transferring new longline technology to small vessels in the northeastern Brazilian pelagic longline fishery. Comparisons of catches between the two recently converted vessels operating across the same spatial and temporal scales showed no significant differences for the main target species, providing evidence to suggest that adoption of the technology was rapid and straightforward. A comparison of relative catch rates between one of the recently converted small longliners and the leased longliner across the same temporal scale, but in different areas, showed that while there were significant differences detected for some species, contributing to a significant reduction in total CPUE, the relative abundance of commercially important species within the operational range of the smaller vessels was sufficient for economically viable catches. The results showed that the net financial profit from the artisanal longliner was almost 10 times greater than that derived from existing fishing methods. The inclusion of some artisanal vessels in this fishery may help address the social and economic problems currently faced by fishing communities in northeastern Brazil.

In an attempt to improve local conditions, during the early 1980's some operators began to investigate alternative fishing methods and, in particular, pelagic longlines to target stocks of highly migratory oceanic groups of species such as tunas (Scombridae), sharks (Carcharhinidae), and billfishes (Istiophoridae and Xiphiidae). A main contributing factor toward investment in this method was the result of earlier exploratory fishing by leased Japanese longliners operating (from the mid 1950's to 1964) throughout the equatorial Atlantic Ocean. Several large (18 m) artisanal vessels from Natal were modified to include Japanese-style mutifilament longlines (details provided by Suzuki et al., 1977; Hazin et al., 1998) and in 1983 began fishing for tuna (mostly yellowfin tuna, *Thunnus albacares*). By 1996, this fleet had expanded to 10 vessels and although there were several shifts in effort on target species during this period (mainly market- oriented and owing to the discovery of new fishing grounds and stocks), few technological advancements in the types of gears used meant that total catch per unit of effort (CPUE = number of fish caught/100 hooks/day) remained fairly stable at about 2.4 (Hazin et al., 1994b, 1998).

While these catches appear quite low, they are comparable to many other pelagic longline fisheries throughout the world (Kawaguchi, 1974; Sakagawa et al., 1987; Uozumi, 1996) and are indicative of the static nature of the fishing gear and low density and foraging behavior of target species. The effectiveness of pelagic longlines is determined by several interrelated factors including the type, size, and spacing of hooks; vertical distribution in relation to maximum abundance of target species; setting time and direction; and, perhaps most importantly, the stimuli associated with bait (Bjordal, 1989; Løkkeborg and Bjordal, 1992; Løkkeborg and Pina, 1997). The integration of these factors in the pelagic longline fishery off northeastern Brazil means that to provide profitable catches, vessels typically have been required to set at least 1,200 hooks over 35 km of mainline. The logistics of manually operating such gear effectively have limited the size of vessels to a minimum of 18 m, precluding adoption of this fishing method by smaller and more common-sized artisanal vessels of between 8 and 12 m.

A lack of local vessels of suitable size led to the leasing of several large (>24 m) foreign longliners in 1996. These vessels were equipped with recent advancements in pelagic longline design, including monofilament mainlines and chemical light sticks located anterior to the hooks and designed to increase fish attraction to the baits. Operating in similar areas as local boats, the leased vessels significantly increased catches of most species and particularly swordfish, *Xiphias gladius*, resulting in the rapid adoption of monofilament mainlines and light sticks by established local operators (Hazin et al., 1998).

The effectiveness of this relatively new configuration of longline provides some justification for a significant reduction in numbers of hooks used by existing vessels. More importantly, reductions in the size of gear required to provide profitable catch rates may facilitate a transfer of effort away from larger vessels to those smaller vessels (<12 m) more commonly used by fishing communities throughout northeastern Brazil, thereby alleviating some of the pressure on stocks of commercially important coastal species. Our aims in the present paper are to provide a preliminary analysis of the potential for such a transfer of effort, by comparing 1) relative catch rates of two recently converted small artisanal vessels (to provide some indication of the ease and practicality of adopting pelagic longlines), 2) catches of one of these small artisanal vessels with a large leased longliner across their respective areas of operation (to quantify relative abundance, distribution, and catch rates of target species), and 3) financial return between an artisanal and leased vessel.

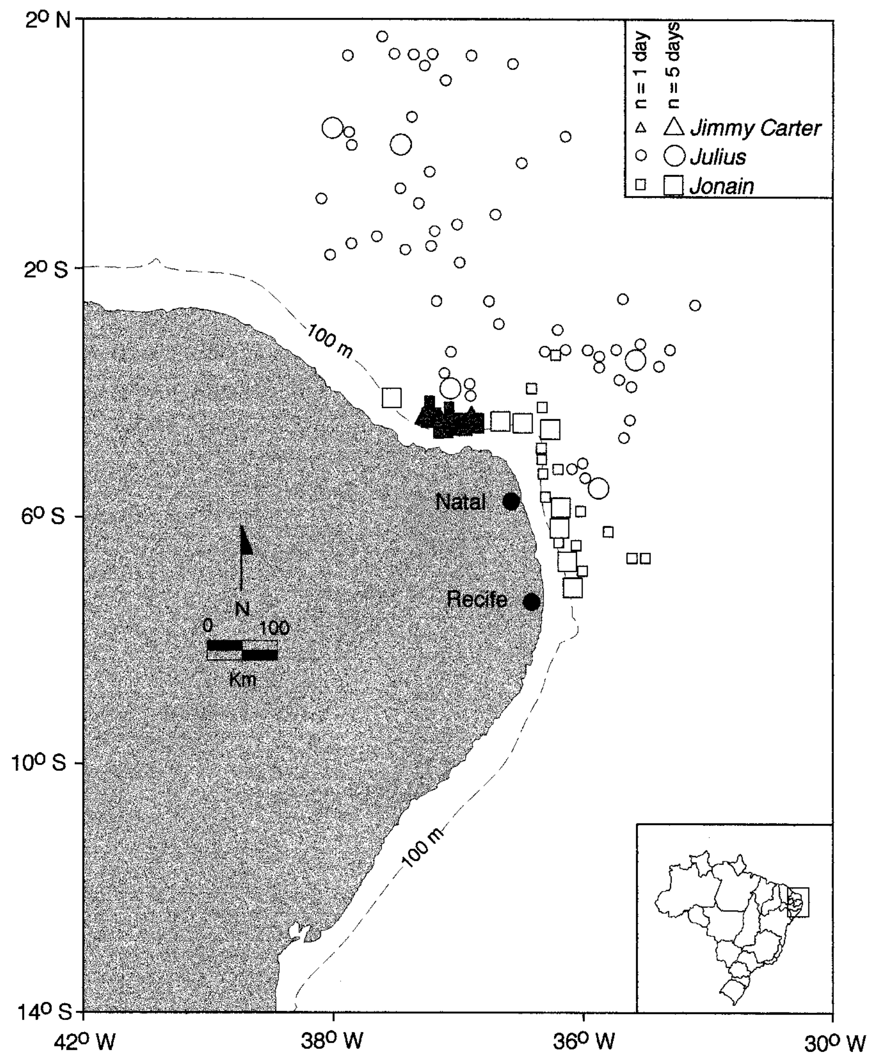

Figure 1.—Location of daily sets of longlines for each vessel during the period examined. The filled squares and triangles represent daily sets of longlines used for the analysis of catches between the *Jonain* and *Jimmy Carter*.

Materials and Methods

This study was done using data collected from two small artisanal longliners (*Jimmy Carter* and *Jonain*, each 12 m in length) and 1 leased American longliner (*Julius*, 24 m in length) operating off the northeast coast of Brazil (Fig. 1) from August 1997 to April 1998. The smaller vessels were almost identical and typical of the artisanal fleet, constructed of wood and powered by small 4-cylinder engines. Their maximum fish storage capacity was 3,000 kg (including ice), and with a crew of 6 they were limited to a maximum of 7 days at sea per trip and an operational range up to 100 km from land. In contrast, the leased vessel was constructed of aluminum, had sufficient space for 40,000 kg of fish, a crew of 8, and autonomy for up to 40 days at sea.

Fishing Gear and Data Collected

The configurations of the longlines used (Fig. 2) were similar across all vessels, with the exception of the length of the mainline and the number of hooks: the *Jonain* and *Jimmy Carter* both used 12 km mainlines with a mean daily number of hooks (± SE) of 289.73 ± 3.22 and 300 ± 0, respectively, while the *Julius* used a 40 km mainline with 1,158.8 ± 21.7 hooks. Each longline consisted of a polyamide (PA) monofilament mainline with a diameter of 4 mm (Fig. 2A).

Secondary lines (PA monofilament 1.8 mm diameter and 15 m in length) were attached with shark clips to the main line at distances of about 35 m (Fig. 2A, B). Styrofoam buoys (about 15 kg buoyancy) each attached to a 20 m line (PA monofilament 1.8 mm diameter) were clipped to the mainline after

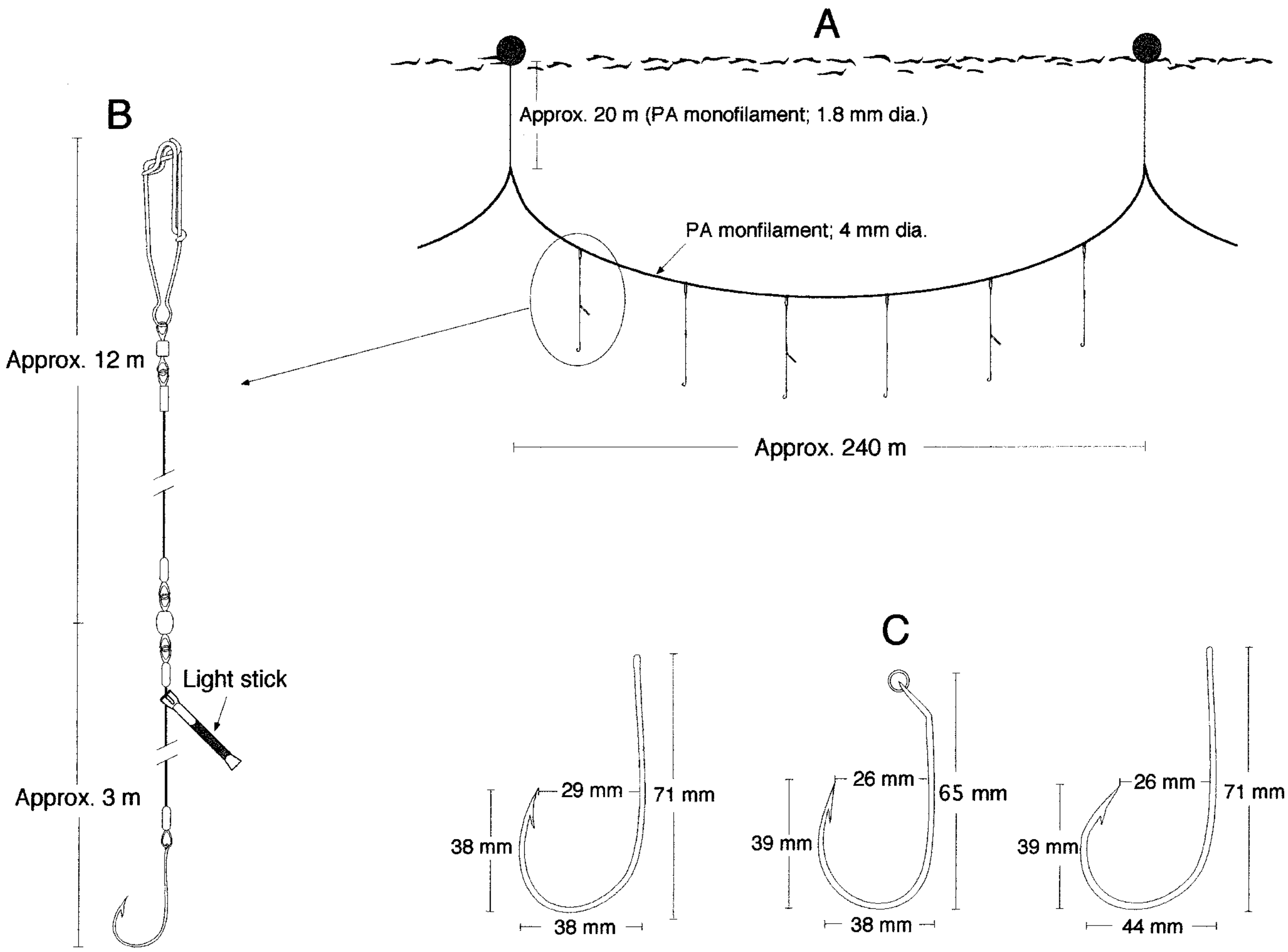

Figure 2.—Diagrammatic representation of A) configuration of pelagic longlines, B) secondary lines, and C) hooks used by all vessels.

every sixth secondary line (Fig. 2A). While the type of hooks used varied among 3 different brands (depending on local availability) their relative sizes remained similar throughout the period examined (Fig. 2C). Hooks were baited with similar-sized (about 140 g) squid, *Illex argentinus*. Light sticks were attached about 3 m above every second hook (Fig. 2B). All longlines were set at between 1600 and 1700 h and retrieved the following morning between 0500 and 0600 h.

Over the period examined (9 months) the number of days fished by each vessel was: 20 (4 trips) for *Jimmy Carter*, 73 (15 trips) for *Jonain*, and 75 (9 trips) for *Julius*. Data were collected from logsheets that vessel operators were lawfully required to complete for each set of the longlines and included location of the longline set, time of setting and retrieval, number of hooks set and configuration (number between buoys), type of bait, and the number of species caught. To provide some verification of catch rates, at the end of each trip the total number of fish unloaded from each vessel was checked against the total numbers derived from the daily logsheets. It was not possible to obtain individual weights of fish caught on each day; only the dressed weights were tabulated after the catch was unloaded from each trip. Further, while individual swordfish were weighed separately, all other species were collectively weighed according to groups (i.e. tunas, billfishes, sharks, and miscellaneous fishes). Sharks and swordfish were weighed without heads or stomachs, other billfishes had their bills removed while all other species were weighed with heads but not stomachs.

Comparison of Two Artisanal Longliners

To investigate relative fishing performance of the two artisanal vessels and so provide some comparative information on the ability of operators to adopt and effectively use longlines, four replicate daily sets of the longlines were randomly selected from three of the earliest trips made by each vessel over the same spatial (Fig. 1) and temporal scales (between 28 Dec 1997 and 2 Mar 1998). Because the number of hooks set on each day were not constant between the two vessels (see above) numbers of fish caught were standardized to catch per unit of effort (CPUE), defined as the number of fish/100 hooks/day. To show that there were no significant differences in soak time (defined as the time elapsed between start of setting and start of hauling) between the various daily sets and trips, these were analyzed using Cochran's test for homogeneity of variances and the appropriate two-factor analysis of variance (soak time was nonsignificant at $P < 0.01$). Daily CPUE values for variables that had sufficient data were then tested for heteroscedasticity, transformed if necessary, and analyzed in the appropriate balanced two-factor analysis of variance.

Comparison of Artisanal and Leased Longliners

To examine the relative economic profitability of artisanal and leased vessels, we calculated the cost of various consumable items (using local prices and based on interviews with vessel owners), including bait, ice, light sticks, fuel, equipment losses, and food pooled across all days fished during the sampled period (73 and 75 days for each vessel, respectively). The total numbers, weights, gross return (calculated using local average market prices for each of the species caught) and net return (derived by subtracting expenditure) were then presented for each vessel.

To provide some comparative information on the relative abundance and distribution of target species and fishing performance of the artisanal and leased longliners in their respective areas (across the same temporal scale), data for variables that had sufficient numbers (occurring in at least 12 replicate daily sets) were first standardized to CPUE (as per above). Because individual fishing trips were not standard across vessels (due to differences in distances traveled, vessel size, and autonomy), they were excluded from analyses and data were pooled across all trips. Equality of soak time was determined using a two-sample unpaired t-test (nonsignificant at $P < 0.01$). Similar analyses were then performed on CPUE data for the various species captured.

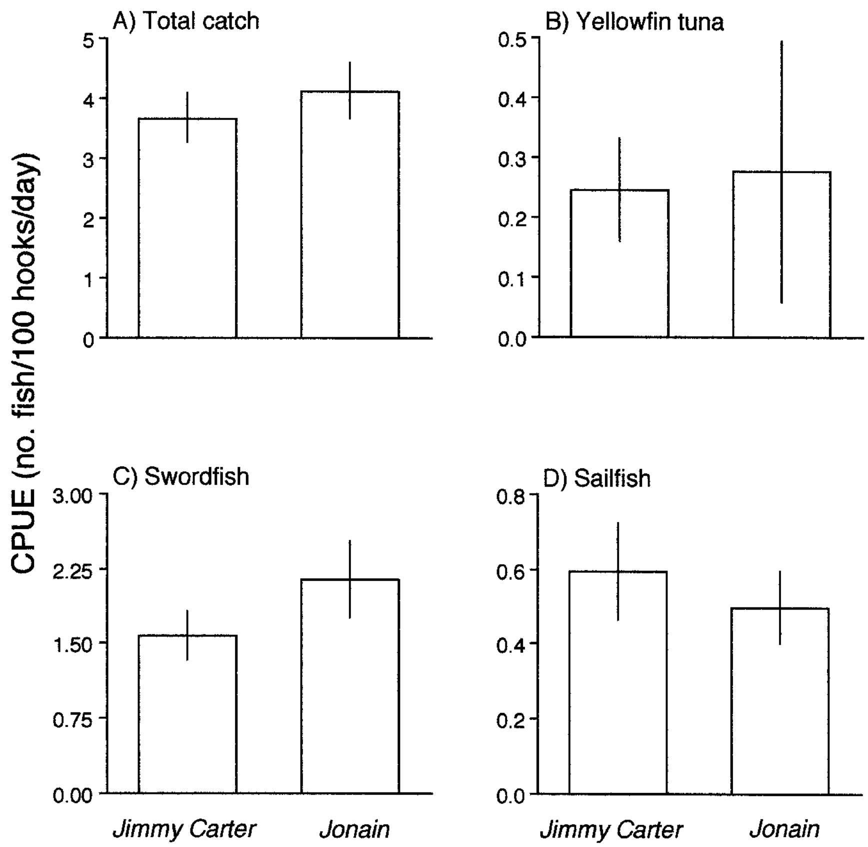

Figure 3.—Differences in arithmetic mean daily CPUE (± SE) of A) total catch, B) yellowfin tuna, C) swordfish, and D) sailfish by the *Jimmy Carter* and *Jonain* across the same spatial and temporal scales.

Table 1.—Summaries of F ratios from analysis of variance to determine effects on CPUE of species due to different longliners (*Jimmy Carter* and *Jonain*) and on different fishing trips. The transforms used to stabilize variances (if required) are also listed.

Source of Variation	df	Total	Yellowfin tuna Sqrt(×)	Swordfish	Sailfish
Longliners	1	0.49	0.40	1.80	1.80
Trips	2	12.53	0.87	0.06	1.14
Interaction	2	0.09	1.41	3.41	1.37
Residual	18				

Results

Comparison of Two Artisanal Longliners

ANOVA comparing CPUE of species between the *Jonain* and *Jimmy Carter* across the same spatial and temporal scales detected no significant effects due to vessels and trips nor any interactions (Table 1). Total CPUE was between 3.8 and 4.1, while the CPUE of individual species ranged from 0.25 (yellowfin tuna) to 2.2 (swordfish) (Fig. 3).

Table 2.—Estimated total costs of consumable items for the *Julius* and *Jonain* over the period examined.

	Julius		*Jonain*	
Item	Quantity	Cost (R$)	Quantity	Cost (R$)
Bait	13,817 (kg)	16,581	3,250 (kg)	3,900
Ice	360,000 (kg)	18,000	45,000 (kg)	2,250
Lightsticks	43,455	36,937	10,575	8,989
Fuel	74,200 (l)	25,970	9,800 (l)	3,430
Lost hooks/ lines		3,178		639
Food		1,802		1,303
Total		102,468		20,511

Comparison of Artisanal and Leased Longliners

Total estimated costs of consumable items and catches and return at point of first sale (pooled across all trips for each vessel) are provided in Tables 2 and 3, respectively. The *Julius* used 86,910 hooks to catch 4,507 fish (114,887 kg) worth R$288,184[1] (net profit of R$185,716 or R$2,476.21 per day fished), while the *Jonain* set 21,150 hooks and caught 792 individual fish (27,547 kg) valued at R$70,565 (net profit of R$50,054 or R$685.67 per day fished) (Table 3).

Compositions of catches by the two vessels in their respective fishing areas were similar among the various groups of species and comprised tunas (>24%), billfishes (>52%), sharks (>14%), and other miscellaneous species of fish (>2%) (Fig. 4). In terms of individual species, swordfish were most dominant, accounting for over 44% of total catch from the *Julius* and greater than 50% from the *Jonain* (Fig. 3B). The only species not represented in catches from both vessels was bigeye thresher, *Alopias superciliosus* (caught only by the *Jonain*) (Fig. 4C).

Two-sample unpaired *t*-tests comparing CPUE between vessels showed that the *Julius* had a significantly greater total catch (5.2) than the *Jonain* (3.8) (Fig. 5A, Table 4) and also increases in albacore, *Thunnus alalunga*; white marlin, *Tetrapturus albidus*; blue marlin, *Markaira nigricans*; blue shark, *Prionace glauca*; and silky shark, *Carcharhinus falciformes* (Fig. 5, Table 4). There were no differences detected between vessels for the catches of swordfish, yellowfin tuna, and bigeye tuna, *Thunnus obesus*; sailfish, *Istiophorus albicans*; other sharks combined, dorado, *Coryphaena hippurus*; and wahoo, *Acanthocybium solandri* (Fig. 5, Table 4).

Table 3.—Total numbers of fish captured, weights of groups of species, and the approximate return at point of first sale for the *Julius* (86,910 hooks) and *Jonain* (21,150 hooks) over the period examined.

	Julius			*Jonain*		
Species	No.	Wt (kg)	R$	No.	Wt (kg)	R$
Tunas						
Yellowfin tuna	383			69		
Albacore	208			16		
Bigeye tuna	585			105		
Subtotal	1,176	31,411	89,521	190	7,395	21,080
Billfishes						
Swordfish	1,922	56,299	159,889	406	15,202	43,174
Sailfish	178					
White marlin	184					
Blue marlin	62					
Subtotal	2,346	65,603	173,839	457	16,539	45,212
Sharks						
Blue shark	438			27		
Night Shark (*Carcharhinus signatus*)	209			2		
Hammerhead sharks (*Sphyrna* spp.)	16			7		
Silky shark	111			34		
Shortfin mako (*Isurus oxyrhincus*)	30			2		
Bigeye thresher	0			6		
Other sharks comb.	88			37		
Subtotal	892	16,675	18,342	115	2,842	3,077
Miscellaneous fishes						
Dorado	62			14		
Wahoo	31			11		
Other fishes combined	0			5		
Subtotal	93	1,198	1,881	30	771	1,196
Total	4,507	114,887	288,184	792	27,547	70,565
Net profit			185,716			50,054

Discussion

The data presented here showed that relatively small (e.g. 12 m) artisanal vessels can effectively adopt small-scale, monofilament longlines and achieve commercially viable catch rates. By comparing the CPUE of one of these vessels against that of a large (24 m) leased longliner across the same temporal scale we have provided a preliminary measure of its performance and economic return as well as information on the relative abundance and distribution of main target species within its limited operational range.

The results of the comparison between the two artisanal vessels operating across similar spatial and temporal scales showed no significant differences for total CPUE (3.8 and 4.2) or any individual species (Fig. 3, Table 1). Because both vessels had almost identical configurations of longlines (i.e. length of mainline, type and size of hooks, bait, etc.), any differences between relative catch rates would have been due to be the skills and experiences of the crew in selecting areas to fish and in setting and retrieving the gear successfully. The observed results, therefore, provide some evidence to suggest that although the fishing method was new, fishermen on both vessels were equally able to comprehend the methods required to effectively determine appropriate areas to fish and operate the gear. In support of this, the CPUE of both vessels was more than 1.6 times greater than the average CPUE achieved in previous years by larger vessels (using multifilament longlines) operating throughout the full range of the fishery (Hazin et al., 1994b). Further, it is apparent that the period required to become proficient in operating the gear was minimal, since the crew of the *Jonain* had over 2 months experience, while the *Jimmy Carter's* first trips were included in the analysis.

Table 4.—Summaries of two-tailed unpaired *t*-tests comparing daily CPUE of the *Julius* (leased vessel) and *Jonain* (artisanal vessel) operating during the same period (df = 146) (t-v = unpaired t-value, significant *P* values are in bold).

CPUE	t-v	*P*
Total	3.665	**0.0003**
Yellowfin tuna	0.914	0.362
Albacore	3.063	**0.002**
Bigeye tuna	1.206	0.230
Swordfish	1.158	0.248
Sailfish	–0.128	0.898
White marlin	6.413	**0.0001**
Blue marlin	3.511	**0.0006**
Blue shark	6.804	**0.0001**
Silky shark	3.121	**0.002**
Other sharks comb.	–1.042	0.299
Dorado	–0.079	0.937
Wahoo	–0.748	0.456

[1] R$288,184 = US$146,645; at the exchange rate of R$1.00 = US$0.513 as of 10 Nov 2000.

A possible contributing factor towards similar catches between the two vessels may have been the relative efficiency of this type of longline configuration, independent of operator skill. Previous studies have suggested that monofilament mainlines have many advantages over the traditional multifilament, including 1) less retention of bait odor (effectively directing fish towards the baited hooks), 2) lower visibility, and 3) less drag during the hooking process, increasing the probability that hooks are imbedded in the mouth of fish as well as transferring their movements along the mainline, providing stimulus for fish attraction (Bjordal, 1989; Hoey, 1995; Sainsbury, 1996). Similarly, light sticks may provide a primary visual stimulus for target species or, alternatively, aggregate smaller bait fish which in turn attract larger species to the vicinity of the baited hooks (Sainsbury, 1996).

Regardless of the specific factors contributing towards the similar fishing performances between the small artisanal vessels, their catch rates during the period examined, combined with the results from the longer-term comparison of catches between the *Julius* and *Jonain* provides some evidence to support involvement in this fishery. Although the total number of fish caught by the *Julius* was much greater than the *Jonain* (Table 3), reflecting absolute differences in numbers of hooks used, the ratios of total catch and financial return to effort were similar. For example, the *Julius* caught 4,507 fish using 86,910 hooks for a return of R$2.14 per hook set while the *Jonain* caught 792 fish with 21,150 hooks and received R$2.36 per hook set. Further, all commercially important species were represented in catches by the Jonain, and although significant differences were detected in the CPUE of some species between vessels (see below), there were no significant differences in the CPUE of main high-value species such as swordfish (accounting for over 50% of total catch from the *Jonain*) and yellowfin tuna and bigeye tuna (Fig. 5E, B, D, Table 4).

Given that the main differences between the *Jonain* and *Julius* were length of mainline and number of hooks set, the significant differences detected in some CPUE's (for mostly lower-valued species) probably reflects species-specific variabilities in relative abundance and distribution between the areas of operation. For example, the *Julius* showed a significant increase in the CPUE of albacore, white marlin, blue marlin, blue shark, and silky shark, contributing to a significant increase in total CPUE (Fig. 5, Table 4). Of these various species,

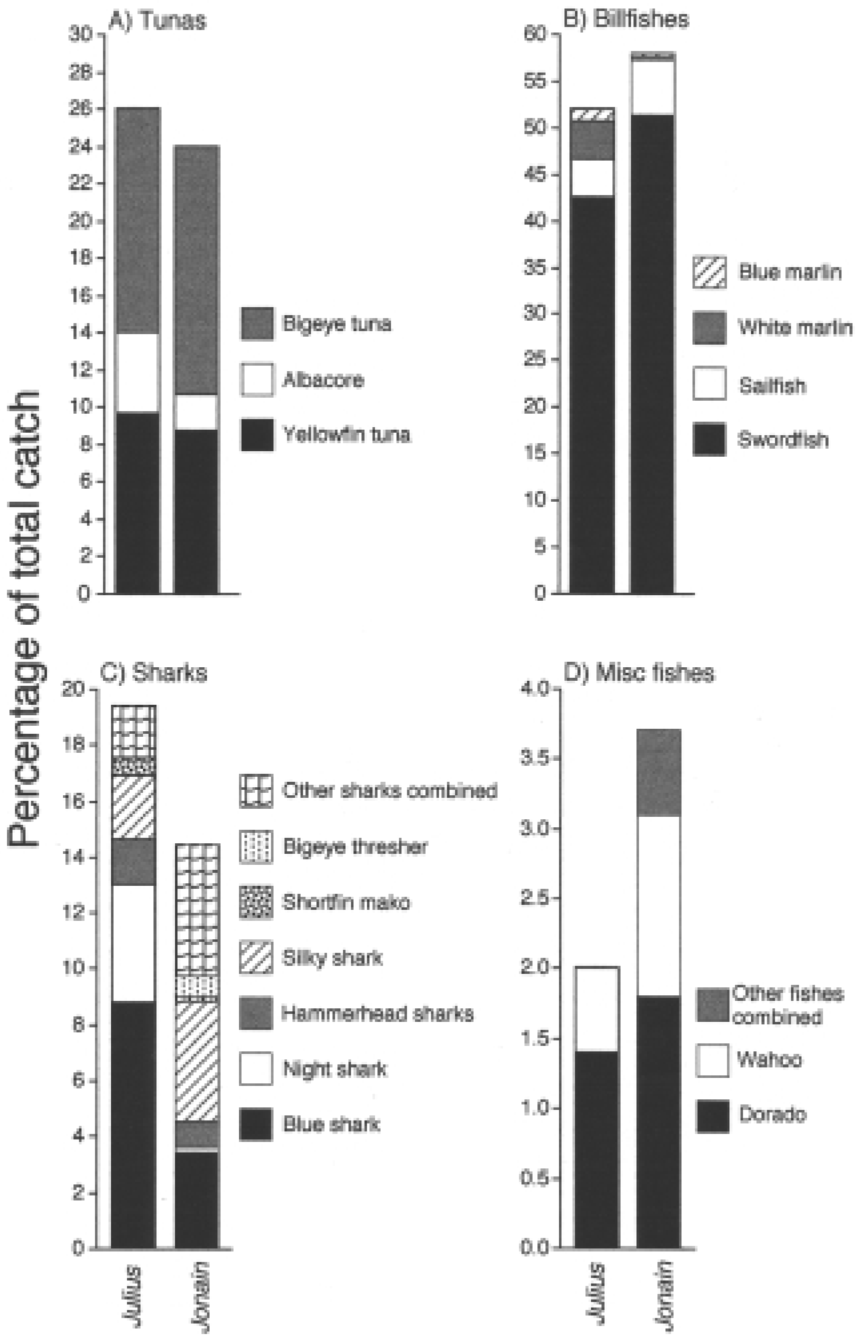

Figure 4.—Percentage composition of A) tunas, B) billfishes, C) sharks, and D) miscellaneous fishes caught by the *Julius* and *Jonain* throughout the total period examined.

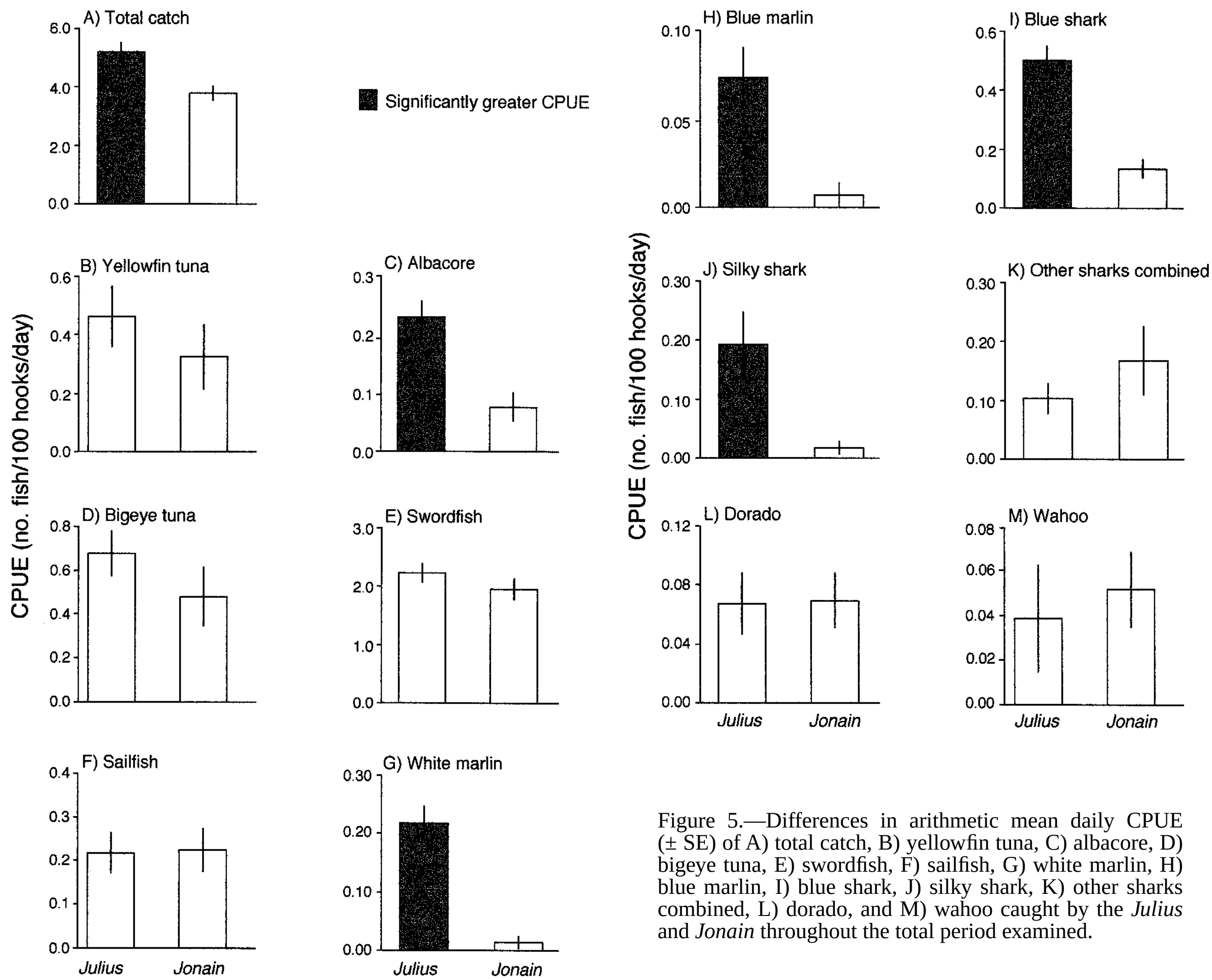

Figure 5.—Differences in arithmetic mean daily CPUE (± SE) of A) total catch, B) yellowfin tuna, C) albacore, D) bigeye tuna, E) swordfish, F) sailfish, G) white marlin, H) blue marlin, I) blue shark, J) silky shark, K) other sharks combined, L) dorado, and M) wahoo caught by the *Julius* and *Jonain* throughout the total period examined.

blue sharks typically are oceanic with an abundance that increases with distance from land (Strassburg, 1958; Hazin et al., 1994a). Similarly, with the exception of sailfish (which showed no significant differences in CPUE between vessels), the species of marlin encountered commonly prefer open ocean and are not usually recorded in shallower areas (i.e. close to the coast) (Nakamura, 1985). The significant increases in CPUE of albacore and silky shark (Fig. 5A, J, Table 4) may be a consequence of fishing in localized areas of maximum abundance, and, in particular, around the many seamounts and shallow banks located well offshore (Travassos et al., 1999 provides details) and outside the operational range of the smaller vessels.

While substantial research is still required to determine the abundance, distribution, and migratory patterns of high-valued target species across the operational range of the smaller vessels (to ascertain levels of acceptable effort), the inclusion of at least some artisanal vessels in this fishery would help address the financial problems faced by fishing communities along the northeast coast of Brazil. For example, Mattos and Hazin (1997) showed that the individual net profit of small artisanal vessels (8–12 m) targeting spiny lobsters over a similar period to that examined in the present study (9 months) was about R$2,520, distributed among three fishermen (i.e. R$840 per fisherman). Excluding the initial costs associated with purchasing the necessary equipment and adapting a vessel for longlining (about R$10,000), the net return from the *Jonain* (R$50,054), represents almost a ten fold increase (i.e. R$8,342 per fisherman). Additional factors supporting a transfer of some effort away from larger vessels (e.g. 18–24 m) might include improved product quality (due to less days spent at sea during each trip), increased business for local suppliers involved in support roles (i.e. shipyards, mechanics, etc.), and perhaps most importantly, a reduction in fishing effort on coastal stocks of traditionally targeted species.

Acknowledgments

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